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CDF

Fully Reconstructed B Decay Results from CDF

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FULLY RECONSTRUCTED B DECAY RESULTS FROM CDF

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We have measured ratios of branching ratios of B mesons including charmonium in the final state and use these ratios to derive B meson branching fractions. Results are also compared to predictions of factorization. We have searched for $B_c^+ \to J/\psi\pi^+$ and set a limit on $\sigma \cdot B$. We observe $\Lambda_b \to J/\psi\Lambda$ and measure the mass $M(\Lambda_b) = 5.623 \pm 0.005 \pm 0.004\,\mathrm{GeV}/c^2$.

As a result of the high b quark production cross section and an efficient dimuon trigger, CDF is a unique environment for study of the color-suppressed $b \to c\bar{c}s$ transition in decay modes that include a charmonium meson in the final state. Precise determination of decay rates in these modes provide tests factorization in B decays, and in the future, they will be used for studies of CP violation. We describe here measurements of relative branching ratios in two-body decay modes that include only charged particles in the final state. There is no identification made of the final-state charged hadrons. The data include $20\,\mathrm{pb}^{-1}$ of $\bar{p}p$ interactions at $\sqrt{s} = 1800\,\mathrm{GeV}$ from Tevatron Collider Run 1a and $90\,\mathrm{pb}^{-1}$ from Run 1b.

The CDF detector is described in detail elsewhere.[1] Features important for the results described here include a central drift chamber and silicon vertex detector (SVX) providing efficient, high-resolutions charged-particle tracking in the pseudorapidity range $|\eta| < 1$ and a trigger system efficienct for muons with $p_T > 2\,\mathrm{GeV}/c$ in the same region.

To reconstruct B or Λ_b candidates, we first search for $J/\psi \to \mu^+\mu^-$ or $\psi(2S) \to \mu^+\mu^-$ candidates. Muons are identified by associating charged tracks in the central drift chamber with track segments in muon chambers behind 4-8 interaction lengths of steel. We require the transverse momentum (p_T) of each muon to be greater than $2\,\mathrm{GeV}/c$ to be in the efficient range of the trigger and that the event pass a dimuon trigger path. We find the mass of the dimuon candidate subject to the constraint that the to muons originate from a common decay vertex with the fit probability $CL(\chi^2)$ required to be greater than 1%. We require the candidate mass to be consistent with the world-average[2] mass. $K_S^0 \to \pi^+\pi^-$ and $\Lambda^0 \to p\pi^+$ candidates[3] are found similarly with the additional requirement that their decay vertex is greater than 1 cm from the beamline in the transverse plane. We then combine J/ψ or $\psi(2S)$ candidates with additional charged-particle tracks or neutral-V candidates and find the B or Λ_b candidate mass subject to the constraints that all tracks (or vees) come from a common decay point, the J/ψ or $\psi(2S)$ has the world average mass, and the momentum of the b-hadron candidate be collinear with the the displacement of the decay vertex from the beamline in the plane transverse to the beamline. The particle mass associated with each track in the reconstruction is assigned based on the decay-mode hypothesis. (The Cabbibo-suppressed $B^+ \to J/\psi\pi^+$ decay is a special case described below.) We again require $CL(\chi^2) > 0.01$ for this second fit. All intermediate states (K^*, ϕ, $\psi(2S) \to J/\psi\pi^+\pi^-$) are required to have masses consistent with the known values. If a $K^{*0} \to K^+\pi^-$ candidate satisfies either set of mass assignments, we choose the assignment with mass closest to the K^* pole mass.

1 Cabbibo-Favored Modes with J/ψ

We measure the relative branching ratios of the Cabbibo-favored decay modes in the $20\,\mathrm{pb}^{-1}$ Run 1a sample. Because the SVX covers only $\pm 25\,\mathrm{cm}$ along the beamline and the rms longitudinal spread of the interaction region is about 30 cm, we do not require all tracks to be reconstructed in the SVX, but use the information if available. From the constrained event fit, we require the the B candidate have a displacement forward of the beamline ($c\tau > 0$). In association with each J/ψ we search for K^+, K_S^0 $K^{*+}(892) \to K_S^0\pi^+$, $K^{*0}(892) \to K^+\pi^-$, and $\phi(1020) \to K^+K^-$ candidates. We find the B yield in each decay mode

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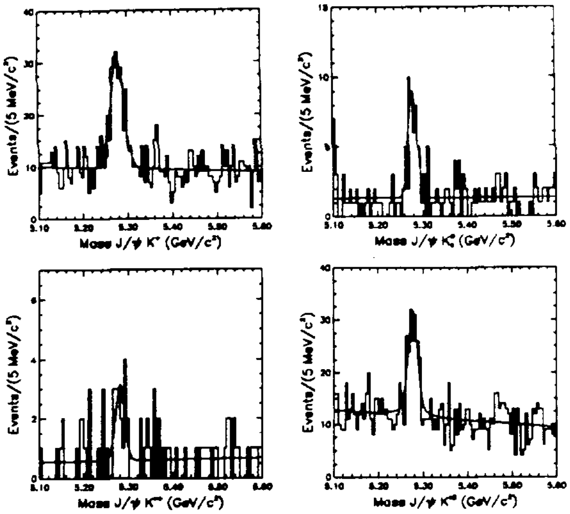

Figure 1: Candidate mass distributions for $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^0$, $B^+ \to J/\psi K^{*+}$, and $B^0 \to J/\psi K^{*0}$.

with a binned likelihood fit to the candidate mass distribution with a linear background function and a Gaussian line shape. The observed yields are:

$$
\begin{aligned}
N(B^0 \to J/\psi K^0_S) &= 36.9 \pm 7.3 \\
N(B^0 \to J/\psi K^{*0}) &= 95.5 \pm 14.3 \\
N(B^+ \to J/\psi K^+) &= 154 \pm 19 \\
N(B^+ \to J/\psi K^{*+}) &= 12.9 \pm 4.3 \\
N(B^0_s \to J/\psi \phi) &= 9.4 \pm 6.2
\end{aligned}
$$

Dividing the yields by the integrated luminosity efficiency for each channel gives $\sigma \cdot \mathcal{B}$, the product of production cross section and branching ratio. Because the B production cross section is not well determined from external measurements, we cannot independently find absolute branching ratios. However, we can find ratios of branching ratios. Also, taking ratios significantly reduces systematic uncertainties due to acceptance and due to trigger and tracking efficiencies. Thus each decay mode is included in a ratio with each of the other three decay modes. We use this information and the world average branching ratios[2] to construct a weighted average branching ratio in each mode, subject to the assumption that as a result of isospin symmetry B^+ and B^0 mesons are produced in equal numbers. The derived branching ratios are:

$$
\begin{aligned}
\mathcal{B}(B^0 \to J/\psi K^0) &= (1.14 \pm 0.27 \pm 0.09) \times 10^{-3} \\
\mathcal{B}(B^0 \to J/\psi K^{*0}) &= (1.39 \pm 0.32 \pm 0.11) \times 10^{-3} \\
\mathcal{B}(B^+ \to J/\psi K^+) &= (0.82 \pm 0.18 \pm 0.07) \times 10^{-3} \\
\mathcal{B}(B^+ \to J/\psi K^{*+}) &= (1.73 \pm 0.55 \pm 0.15) \times 10^{-3}
\end{aligned}
$$

We derive the Vector-Pseudoscalar decay ratio

$$\frac{\mathcal{B}(B \to J/\psi K^*)}{\mathcal{B}(B \to J/\psi K)} = 1.36 \pm 0.24 \pm 0.25$$

which can be compared to the factorization prediction of[4] 1.61.

We also calculate the strange-quark fragmentation fraction in b jets from the efficiency-corrected yields, the world-average B^+ and B^0 branching ratios, the world-average lifetime ratio $\tau(B_s)/\tau(B)$ and theoretical predictions [5] for the decay widths $\Gamma(B_s \to J/\psi\phi)$ and $\Gamma(B \to J/\psi K^{(*)})$ and find $f_s = (0.34 \pm 0.10 \pm 0.03) f_{u,d}$, where f_q is the fraction of B mesons produced including quark q and we assume $f_u = f_d$.

2 Cabbibo-Favored Modes with $\psi(2S)$

Using the full 110 pb^{-1} sample, we measure branching ratios for B decays including a $\psi(2S)$ normalized to similar J/ψ decay modes so that efficiency and production uncertainties cancel. We reconstruct both $\psi(2S) \to J/\psi\pi^+\pi^-$ and $\psi(2S) \to \mu^+\mu^-$. In order to reduce backgrounds, we require that all tracks be reconstructed in the SVX

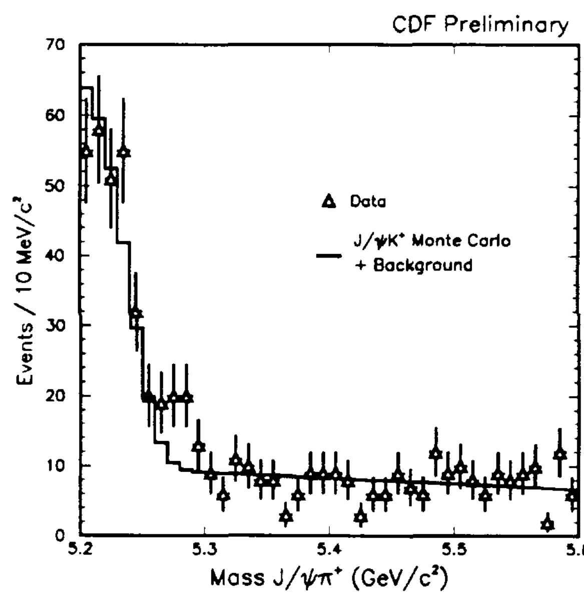

Figure 2: The points show the $B^+ \to J/\psi\pi^+$ candidate mass distribution. The line is the $J/\psi K$ and background contributions from the fit projected onto $M(J/\psi\pi)$.

and that the proper decay length $c\tau$ of the B candidate from the constrained fit be greater than $100\,\mu$m. We also require that the B candidate be isolated such that $\sum \hat{p}_B \cdot \vec{p}_i < 0.8|\vec{p}_B|$ where $\vec{p}_B$ is the B candidate momentum and the $\vec{p}_i$ are the momenta of additional charged tracks within a cone $R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 1$ around the B candidate. Except for the additional mass requirement in the $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ decay, we use the same cuts for the B decay modes including a J/ψ or a $\psi(2S)$. After weighting by the J/ψ and $\psi(2S)$ branching ratios and relative reconstruction and trigger efficiencies, we measure

$$R = \frac{B(B^+ \rightarrow \psi(2S)K^+)}{B(B^+ \rightarrow J/\psi K^+)} = 0.67 \pm 0.09 \pm 0.10$$

$$R^* = \frac{B(B^+ \rightarrow \psi(2S)K^{*0})}{B(B^+ \rightarrow J/\psi K^{*0})} = 0.57 \pm 0.13 \pm 0.07$$

As a test of the factorization hypothesis, these results can be compared to theoretical predictions [6] of $R = 0.59 \pm 0.07$ assuming a dipole structure to the form factor and $0.25 \leq R^* \leq 0.67$.

3 Cabbibo-Suppressed Decay $B^+ \rightarrow J/\psi\pi^+$

$B^+ \rightarrow J/\psi\pi^+$ is a possible channel for observation of direct CP violation because suppression of the dominant spectator amplitude enhances interference with nonleptonic penguin amplitudes.[7] We discriminate between this decay mode and the dominant $B^+ \rightarrow J/\psi K^+$ solely on the basis of B mass reconstruction with π and K hypotheses. $J/\psi\pi$ events would be distributed in a broad tail at high mass in the $J/\psi K$ distributions discussed in the previous sections. Events are reconstructed in the full $110\,\text{pb}^{-1}$ sample. All three charged tracks must be reconstructed in the SVX, and the flight distance of the B candidate must be at least $150\,\mu$m from the beamline. To extract the relative branching ratios, we perform an unbinned likelihood fit in $M(\psi K)$ and $M(\psi\pi)$ to a Gaussian signal in the two mass reconstructions and a linear background in $M(\psi K)$. We find a $J/\psi\pi$ yield of 28^{+10}_{-9} events. The $J/\psi\pi$ mass distribution is shown in Figure 2. The fitting technique was tested with 10 sets of 1000 Monte Carlo simulated events with various values of the background fraction and relative branching ratio. We correct for the different pion and kaon decay probabilities and find

$$\frac{B(B^+ \rightarrow J/\psi\pi^+)}{B(B^+ \rightarrow J/\psi K^+)} = 0.060^{+0.022}_{-0.020} \pm 0.001$$

where the systematic uncertainties arise from variation of background parameterization and the decay-in-flight correction.

4 Search for $B_c^+ \rightarrow J/\psi\pi^+$

We see no evidence for an enhancement in high-mass $J/\psi\pi^+$ candidates and set limits for the product of the production cross section and branching ratio relative to $B^+ \rightarrow J/\psi K^+$. The search includes the full $110\,\text{pb}^{-1}$ sample, and all three charged tracks in each candidate must be reconstructed in the SVX. To reduce backgrounds, we apply a cut on the proper decay length. The lifetime of the B_c^+ is unknown and is predicted[8] to be between 0.4 ps and 1.4 ps. The efficiency of the flight distance cut depends on the assumed lifetime. We set limits for 7 lifetime values between 0.2 ps and 1.6 ps using 4 different $c\tau$ cuts between $60\,\mu$m and $150\,\mu$m.

Monte Carlo simulations predict the B_c mass resolution to be $20\,\text{MeV}/c^2$. For each value of the $c\tau$ cut, we find the $80\,\text{MeV}/c^2$ region with the most candidates within $150\,\text{MeV}/c^2$ of the theoretically predicted[9] mass of 6s258 GeV/c^2 and estimate the background from a linear fit to the masses of the remaining candidates in the range 6-7 GeV/c^2. After correction for relative efficiencies, we derive the 95% confidence level upper limit

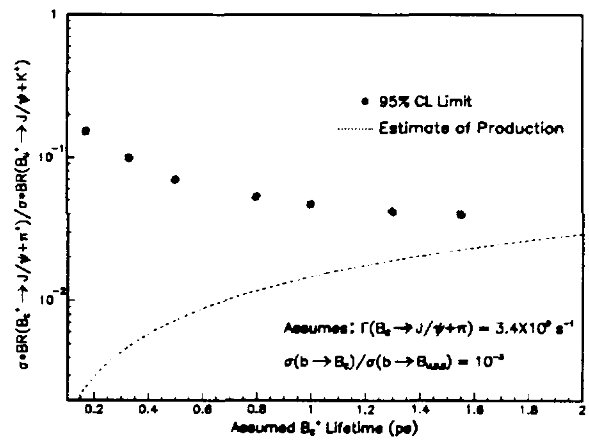

Figure 3: 95% confidence level upper limit on B_c+ production relative to B^+ as a function of assumed lifetime. The dashed line represents the prediction of this ratio subject to the assumption that B_c production[10] is 0.0015 times as likely as all other B mesons and that decay width[11] is $\Gamma(B_c^+ \rightarrow J/\psi\pi^+) = 4.2 \times 10^9\,\text{s}^{-1}$.

$$\frac{\sigma(\bar{p}p \to B_c^+ X) \cdot \mathcal{B}(B_c^+ \to J/\psi \pi^+)}{\sigma(\bar{p}p \to B^+ X) \cdot \mathcal{B}(B^+ \to J/\psi K^+)} < 0.1$$

for B_c lifetime greater than 0.33 ps. The results as a function of lifetime are displayed in Figure 3. The limit calculation includes the statistical uncertainty on the $B^+ \to J/\psi K^+$ yield and a 6% systematic uncertainty from the relative trigger efficiencies and from the B_c momentum spectrum.

5 Observation of $\Lambda_b \to J/\psi \Lambda$

The decay chain $B^0 \to J/\psi K_S^0, K_S^0 \to \pi^+\pi^-$ provides the normalization for the topologically similar $\Lambda_b^0 \to J/\psi \Lambda^0, \Lambda^0 \to p\pi^-$ decay. In the Λ reconstruction, the proton is assumed to be the leading particle, and to insure good efficiency, we require $p_T > 0.4\,\mathrm{GeV}/c$ for the pion. We require the muons to be reconstructed in the SVX and apply a $c\tau > 100\,\mu$m decay-length cut and make stringent trigger selection cuts. We observe 7.8 ± 3.4 Λ_b candidates and 57.6 ± 8.7 B^0 candidates in the $110\,\mathrm{pb}^{-1}$ sample. Correction for relative efficiencies gives the production ratio:

$$\frac{\sigma(\bar{p}p \to \Lambda_b^0 X) \cdot \mathcal{B}(\Lambda_b \to J/\psi \Lambda^0)}{\sigma(\bar{p}p \to B^0 X) \cdot \mathcal{B}(B^0 \to J/\psi K_S^0)} = 0.27 \pm 0.12 \pm 0.07$$

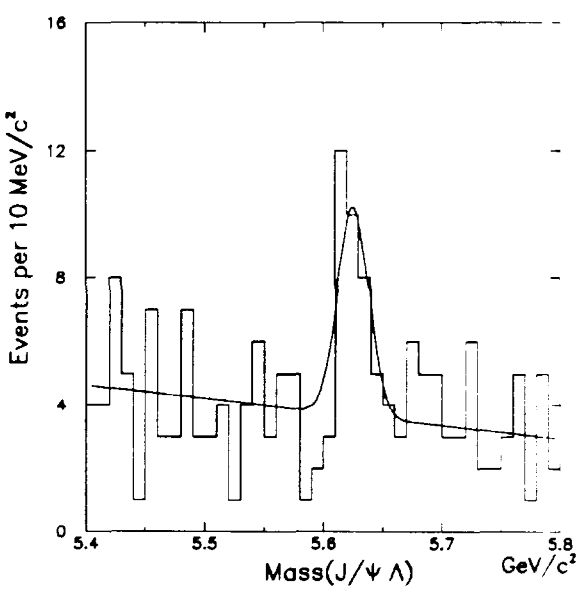

Figure 4: $J/\psi \Lambda^0$ mass distribution with loose cuts. The line shows the result of the fit for the mass.

where the dominant systematic uncertainties arise from the unknown Λ_b polarization and $b \to \Lambda_b$ fragmentation spectrum. If we assume that the fragmentation fractions are $f(B) = 0.375$ and $f(\Lambda_b) = 0.1$, the branching ratio is $\mathcal{B}(\Lambda_b \to J/\psi \Lambda) = (4.3 \pm 2.1 \pm 0.8) \times 10^{-4}$.

We relax the trigger selection and momentum requirements and consider events without SVX information and find a yield of 19.9 ± 6.4 events in an unbinned likelihood fit. The Λ_b mass is found to be $M(\Lambda_b) = 5.623 \pm 0.005 \pm 0.004\,\mathrm{GeV}/c^2$. The systematic uncertainties are determined from studies of the inclusive J/ψ sample, as in the previous CDF measurement of the B_s mass.[12] Systematic uncertainties cancel in a direct comparison the the B^0 mass measured in $J/\psi K_S^0$ decays, and we find the mass difference $M(\Lambda_b) - M(B^0) = 0.342 \pm 0.006\,\mathrm{GeV}/c^2$.

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